Predictive Modeling Of MEMS-Hotplates - From Inverse Modeling To Experimental Validation

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Abstract

This work presents a comprehensive modeling and validation study of MEMS-based infrared (IR) emitter chips using a neural network-assisted inverse modeling approach in COMSOL Multiphysics. Starting from a single baseline chip geometry, a simulation model was developed that captures the coupled thermal and electrical behavior of a microfabricated MEMS hotplate designed to function as a broadband IR emitter.

A key step in the model building was the inverse problem formulation: material parameters that are difficult or impossible to access directly through measurement were estimated by training a neural network on experimental data from a fabricated reference chip. Through an iterative process, the network adjusted the simulation input parameters to minimize the deviation between simulated and measured functional properties. This approach enabled an accurate COMSOL model that reflects the true behavior of the emitter chip across relevant operating conditions.

Using the validated model, a broad simulation study was conducted to explore the influence of geometric variations on the emitter's performance. The layout e.g. chip dimensions, membrane size and heater width were systematically varied to explore performance optimization for different application scenarios. Moreover, "Surrogate Modeling" was utilized to access the characteristics of a wider range of parameter combinations, particularly focusing on properties such as service life as a function of driving electrical power.

Selected geometries identified through simulation as promising candidates were subsequently fabricated and experimentally characterized. Key properties characterized include the dependence of temperature and electrical resistance on input power, steady-state radiant flux, time-resolved emission profiles, and emitter behavior under various pulsing frequencies.

Finally, simulation predictions and experimental results were systematically compared for a wide set of chip variants. The correlation between predicted and measured IR emission characteristics - such as power output, transient response, cutoff frequency, and temperature-dependent resistance - is discussed in detail. While some properties show strong agreement, e.g., the time dependence of the peak-to-peak intensity, others, such as the absolute radiant flux, show only qualitative agreement.

This study demonstrates the potential and current limitations of neural network-assisted inverse modeling for functional MEMS design. It highlights how accurate simulation models can significantly accelerate the design iteration cycle and support predictive fabrication of performance-optimized IR emitter devices.

Figures used in the abstract

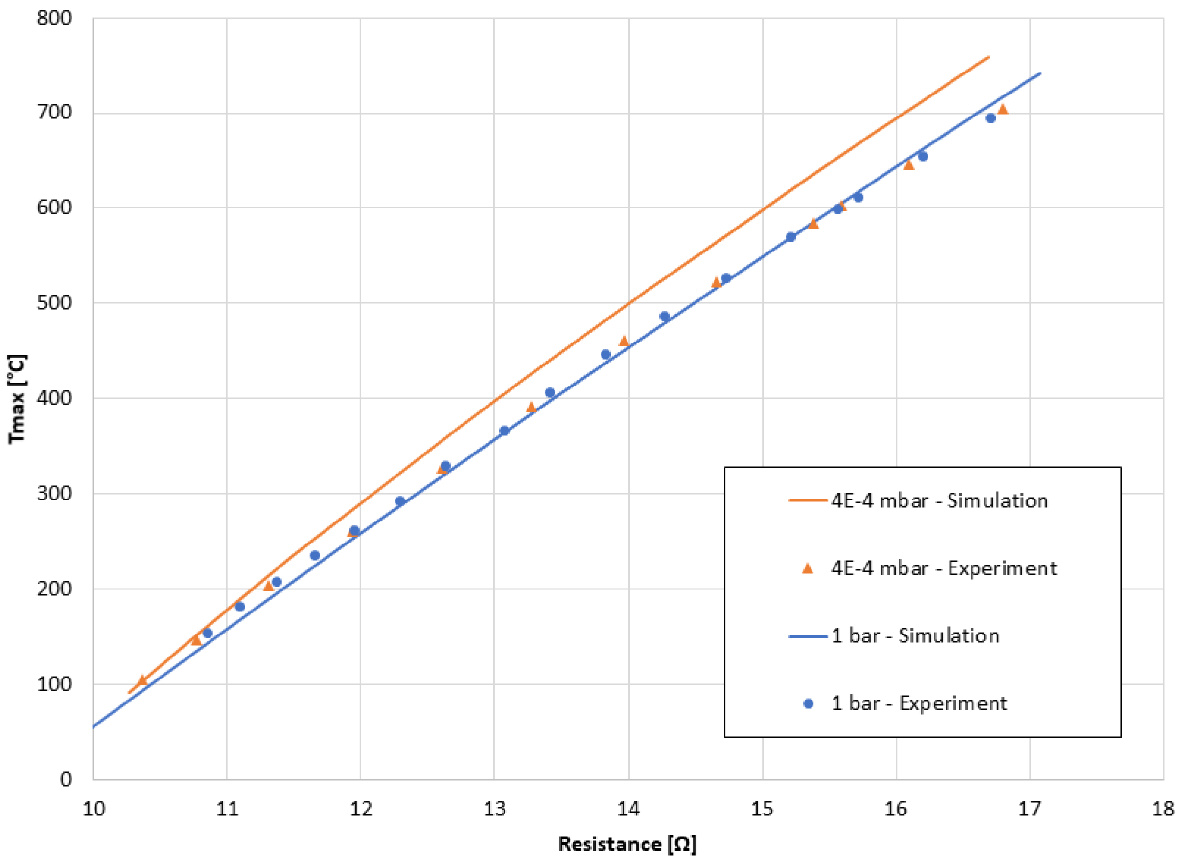

Figure 1 : Comparison of experimental and simulated data for the reference chip after initial model building. Dotted lines represent experimental results, while solid lines indicate simulation outputs, under vacuum conditions (blue) and ambient pressure (orange).

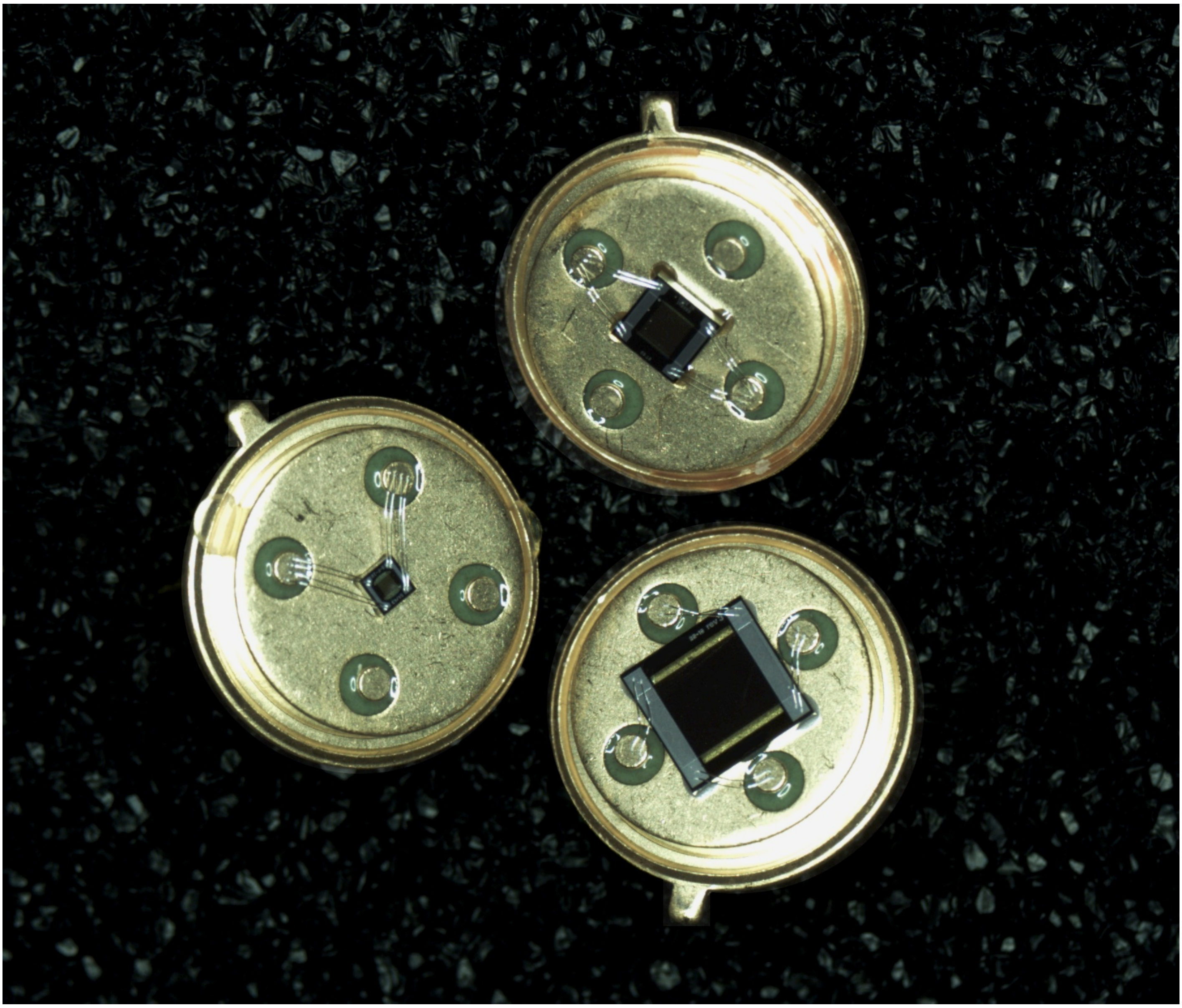

Figure 2 : Three different sizes of the MEMS-IR emitters. The large chip in the bottom right is the reference type, which served as the basis for the COMSOL model.

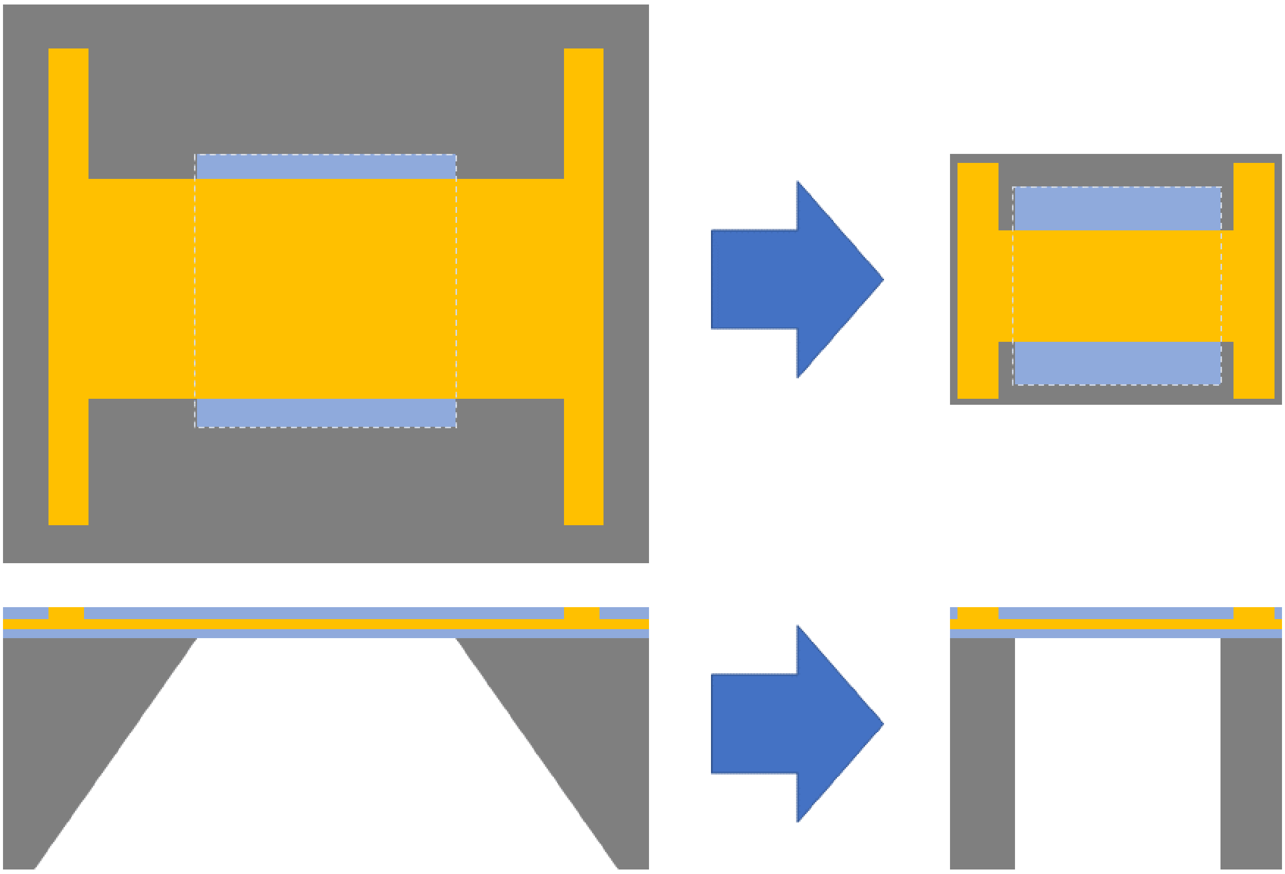

Figure 3 : Schematic representation of the reference chip compared to a newly developed design

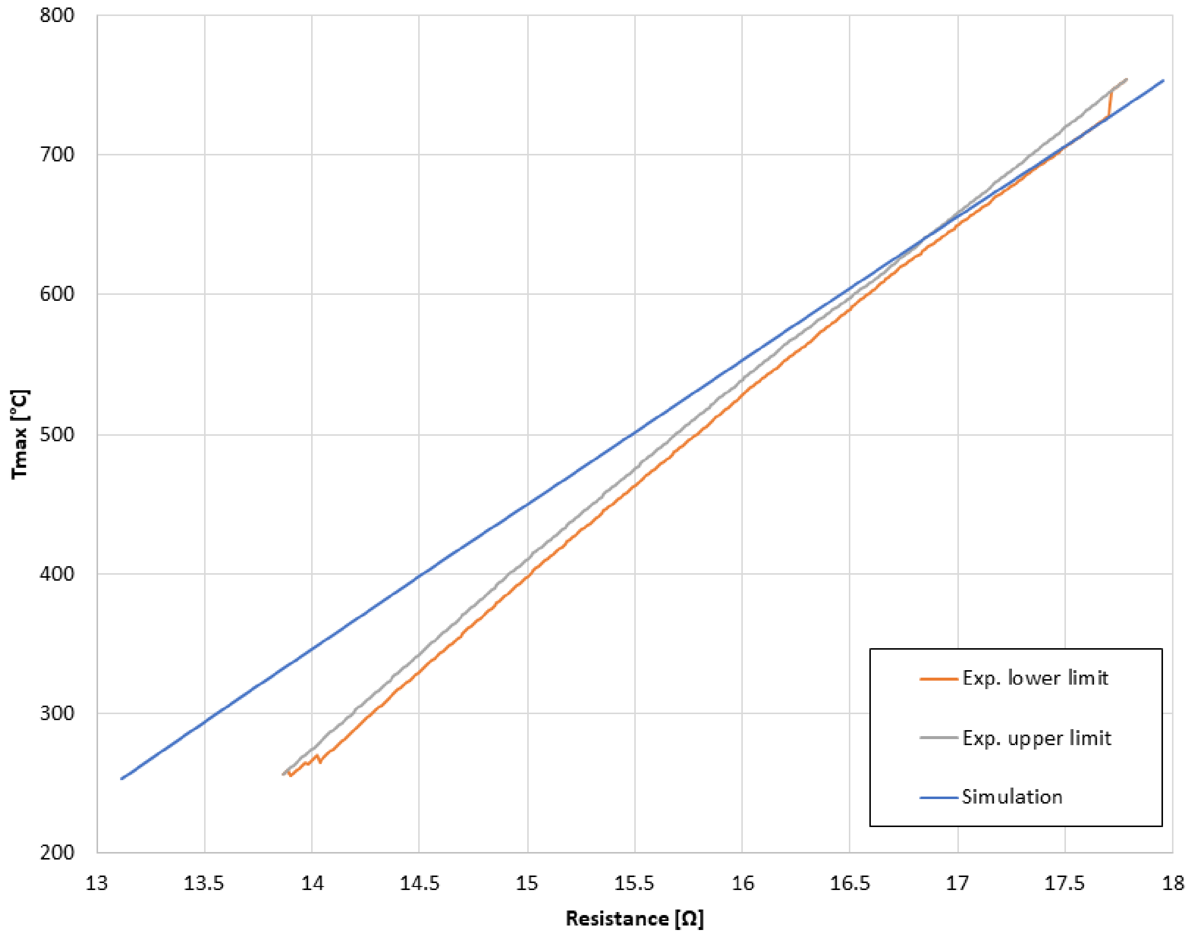

Figure 4 : Comparison of the temperature-to-resistance-dependency of a newly developed chip with differenz size and straight walls